HEAT SOURCES FOR SPACE MANUFACTURING PROCESSES

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ABSTRACT

This paper examines the various possible heat sources for manufacturing processes requiring heat in the environment of space and zero-G and makes a rough analysis of the usefulness of the heat sources with respect to weight, bulk, power requirements, reliability, safety of operation, and cost where applicable to any of the various manufacturing process experiments proposed for the AAP program.

The analysis of the heat sources is not too detailed or accurate because not enough is known at this time about which materials are to be processed.

This paper also assumes that a primary source of electric power is available, large enough to meet the demand in each instance.

INTRODUCTION

Almost everyone recognizes that space offers some unique properties for certain manufacturing processes. These are zero-G and a vacuum pump of infinite capacity. Accordingly, various experiments have been proposed to determine if these properties can be exploited for manufacturing unique products. We should also recognize that it is the liquid state

of matter that offers the best properties for the zero-G environment. Gases and solids are not affected very much by zero-G.

It should be made clear at this time that the heat sources referred to in this paper, except for solar radiation and hot gases, are not primary. For the purposes of this paper, we shall assume that there is a prime source of electric power available. Obviously, the electric power source, for the first experiments at least will be severely limited, therefore, the heat source chosen should be the most efficient for the particular process involved.

We don't know at this time which processes will be the most fruitful and therefore a series of experiments have been proposed to determine this. A test chamber has been designed and built which utilizes an electron beam gun for a heat source and it is intended that this will be orbited on the AAP-1 flight. This chamber has facilities for several manufacturing experiments. The experiments approved for this flight are:

1. Exothermic Brazing (Exp. #492)
2. Electron Beam Welding (Exp. #493)

Additional proposed experiments are:

1. Single Crystal Growth
2. Casting of Composite Materials
3. Casting Spheres
4. Manufacture of Amorphous High Index Glass

In the meantime the design of a second generation manufacturing chamber has been started. This chamber is to have many more manufacturing capabilities than the first chamber including multiple heat sources, hence the need for our examination of various heat sources for their greatest usefulness.

This new chamber, which is a prototype, will teach us what we need to know about the final design of such a chamber. It will certainly allow us to make empirical experiments to determine exact heat requirements, heat transfer rates, cooling requirements and contamination potential of each experiment. The chamber is designed with a jacket which can be pumped down to a vacuum for insulating purposes or filled with liquid nitrogen to provide a cold wall. The interior of the chamber will be pumped by a 6 inch diffusion pump and the jacket by a 2 inch diffusion pump. The dimensions inside will be approximately 4 ft. long by 26 inches in diameter since the shape will be cylindrical.

Every BTU must be accounted for because a space station is a closed environment and if the heat generated by the manufacturing process is not radiated off into space or dumped into a heat sink which is thrown

away, the heat will appear in the space station. Insulating the chamber merely delays the matter. It is mandatory that calculations and experiments be undertaken to determine if the space station will radiate this heat away without making the environment uncomfortably hot for the astronauts. If it will not then the heat must be rejected by some method yet to be determined.

First slide.

Since most manufacturing processes require the use of heat as a necessary adjunct to the process itself, let us take a hard look at various sources of heat to select the best candidates for use in space.

Slide #1

1. Induction Heating
2. Electron Beam Gun
3. Electron Beam Plasma Gun
4. Laser
5. Electric Arc
6. Hot Gas
7. Electrical Resistance
8. Solar Radiation
9. Chemical
10. Ultrasonics
11. Infra-red Radiation
12. Microwave Radiation

The sources shown were examined, when significant, for their weight, efficiency, bulk, time to product the heat required, power requirements ancillary equipment needed, complexity of operation construction and control, contamination hazards, reliability, training required to use, operator skill and cost. We don't consider this list as final. Other heating methods will be examined when they become candidates.

The sources best suited for space use turned out to be-

Induction Heating
Electron Beam
Electrical Resistance
Chemical

The chemical heat is good for short term heating because it makes no demand on the spacecraft power system.

Electrical resistance and the electron beam are efficient and are practical to use from the standpoint of cleanliness and their adaptability to vacuum use.

Induction heating is important because the coils used for heating can be also used for levitating the object to be heated and thus give us management of position and movement except with non-conductors. The process is also about 70% efficient.

When the coils are properly spaced, this system of heating has the possibility of producing convenient temperature gradients in experimental materials.

It is impossible in the time alloted to go into the calculations which were used to evaluate each heat source. All we can do is give some evaluation of the results.

The heat sources eliminated were rejected for the following reasons:

The electron beam plasma gun is more complicated to operate than the electron beam gun and gives no special advantage for the present proposed experiments. It may be used on some later experiment which requires it.

The laser was rejected because of its poor efficiency. The most efficient laser is the CO_2 laser and it is only 14% efficient. On these first experiments, we have no power to waste. Also that energy which doesn't go into the laser beam will largely appear in the spacecraft, which is highly undesirable.

The electric arc was rejected because, so far, all the experiments proposed are to be done in a vacuum, and of course, the electric arc will not work in a vacuum.

The use of a hot gas, which means fuel and oxidizer gases, was rejected at this time for safety reasons.

Solar radiation would be very awkward to use unless the spacecraft maintains a constant orientation to the sun. At the very least, it would require a rather elaborate optical system to place the heat at the spot where it is needed.

Ultrasonics are also very inefficient and require a rubbing contact. They were rejected for these reasons.

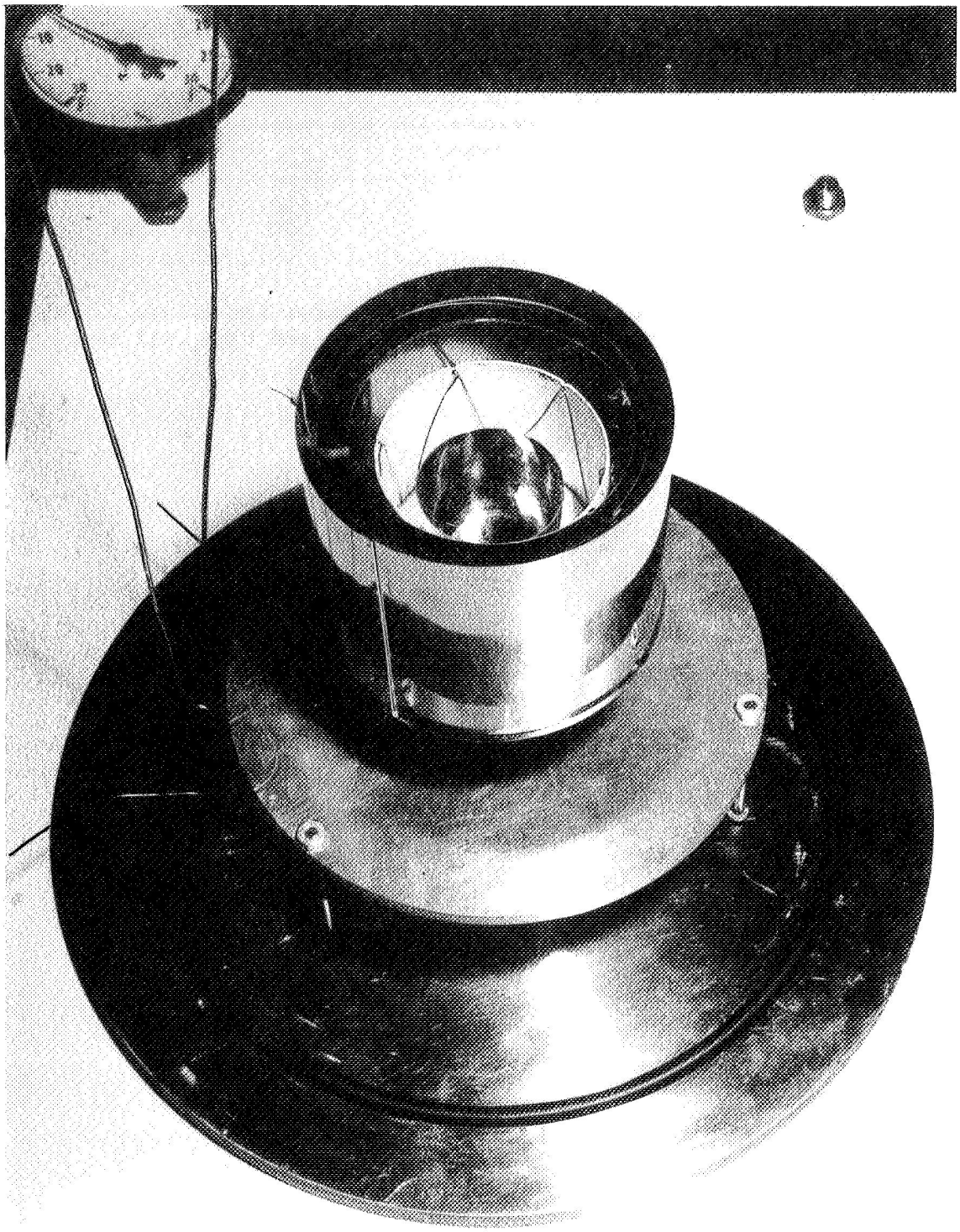
Infra-red radiation from lamps may prove to be a good heat source for later experiments particularly where heat is required over a large area, but for high temperature work where metals are to be melted, the lamps are too awkward to use.

Microwave radiation requires a powerful transmitter for heating so its weight efficiency is poor but it may be used at a time when the heating of non-metallic substances is required.

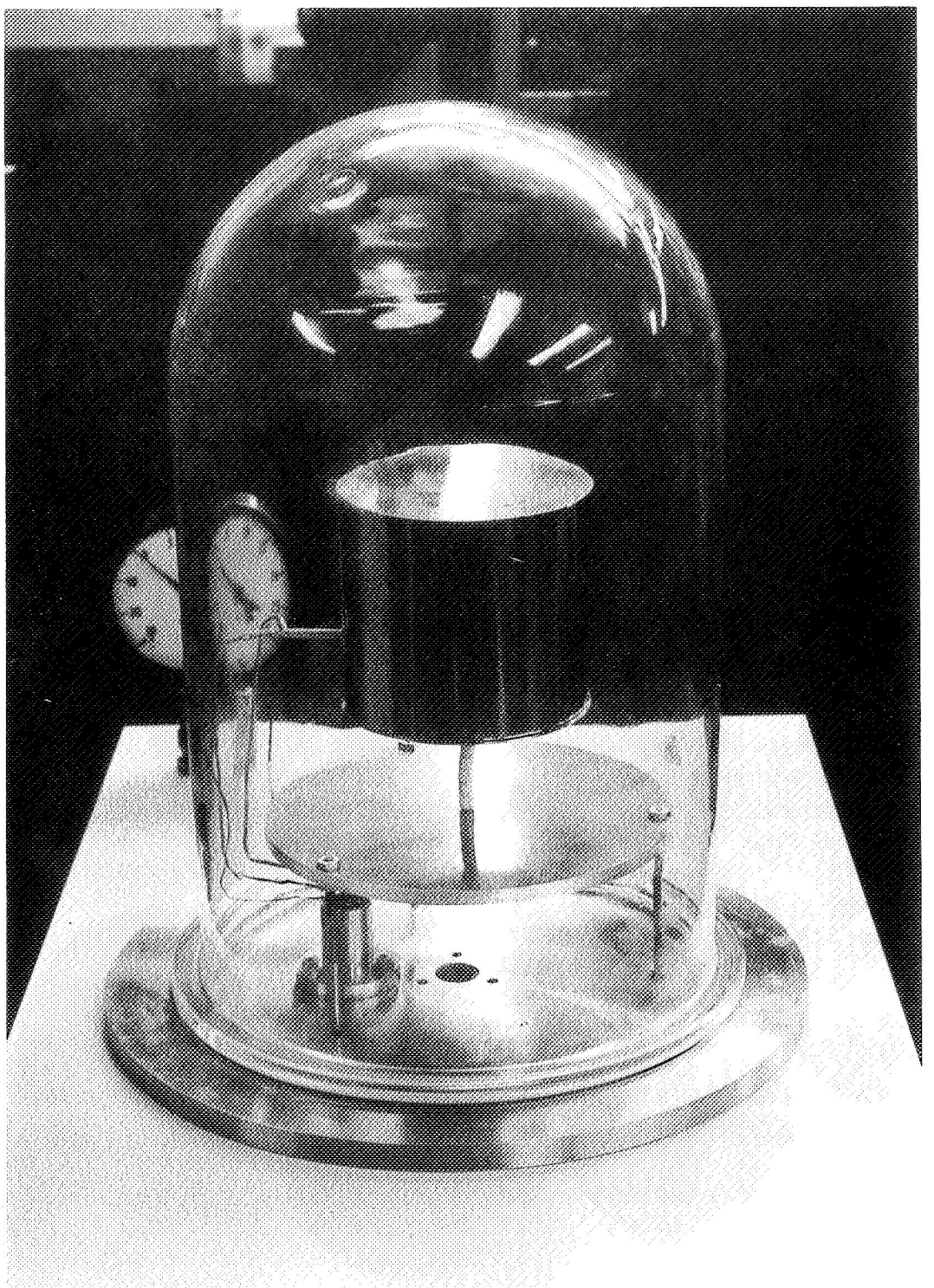
Let us take a look at a typical heat source in its prototype stage. This heat source was developed by the author in the Manufacturing Engineering Laboratory and was developed for the purpose of melting 5 cubic centimeter glass samples in space.

Slide #2
Slide #3
Slide #4

To finish, let me say that the study of heat sources for manufacturing in space processes has just started. Much effort and time will have to be expended before the art becomes routine.



SLIDE 2



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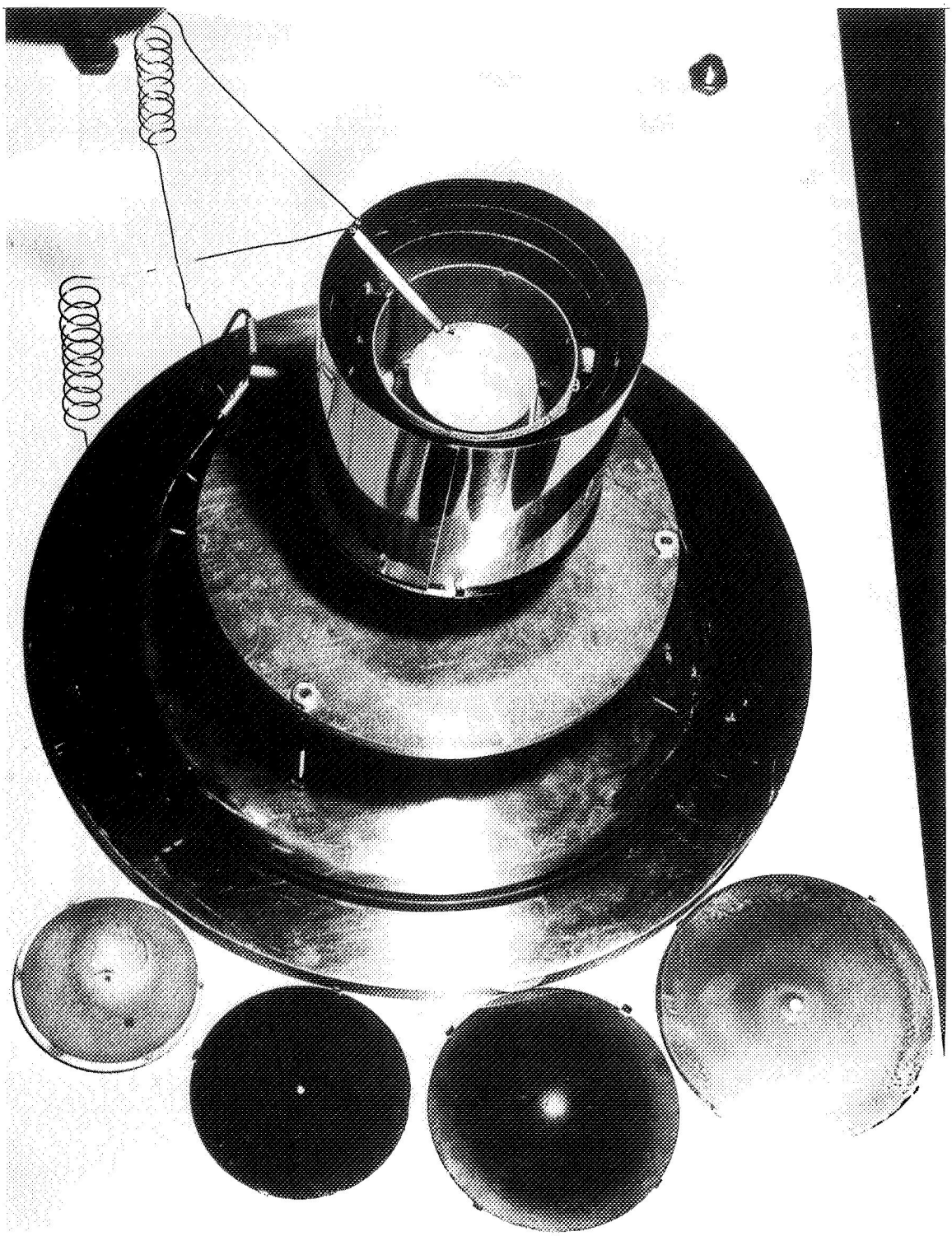

SLIDE 4